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Study of degradation of a grid connected photovoltaic system

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Abstract

Performance of photovoltaic (PV) systems degrades due to the technology and the operating conditions. The degradation of is one of the key indicators for reliability assessment of a PV system. This paper presents a degradation study of the grid connected PV system located in the campus of the University of Salento. A comparative analysis of actual and theoretical output power is carried out over a monitoring period of five years. PVsyst software is chosen to simulate the output power using actual meteorological data. The hourly expected power generation index is introduced to investigate on degradation and reliability.

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Keywords: Photovoltaic, Grid connected, Simulation, Reliability, Degradation, PVsyst

1. Introduction

The modern energy management systems can contribute to increase PV power generation in the small scale grid by providing a strategic support for control and monitoring of the renewable energy systems [1]. In fact the data collecting from technological devices as environmental sensors, inverters and meters can support the PV generation predictions that is an essential task for high integration into the electricity network [2][3]. Furthermore the data processing and analysis, come from the monitoring of PV systems, enable to assess the performance of grid-connected PV systems [4] and to investigate the impacts of the weather variables as solar irradiance and ambient

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temperature on the photovoltaic generation prediction [5] [6]. The PV generation forecasting is a complex task, considering stochastic impact of weather conditions on the prediction accuracy [7] [8] and the effect of the performance degradation of the PV systems due to shadows, soiling and system component faults. The degradation causes a loss of power and consequently a decreasing of performance over the time. It is present at all levels of the whole system and depends on technology and operating conditions. The degradation is one of the main factors for reliability assessment of a photovoltaic system.

Generally, the reliability of a system is the ability to perform a defined function in a perfect manner. In the case of the electrical generation by photovoltaic source, the randomness of solar irradiance causes fluctuations of the power output, impacting on the reliability of such system. A wide spread of the PV generation can generate negative effects on the power distribution network as voltage fluctuation and reverse power flows, which are not inadmissible to ensure a stable supply of energy, causing also the increasing of the maintenance costs and the risk of power outages. Reliability is one of the main indicators to assess the effects of the renewable generation in the distribution networks in term of the cost and the power outage.

In this context, methodologies and tools to quantify the reliability of grid-connected PV systems are needed [9]. The degradation studies can support the reliability assessment of the PV system. Previous works have already demonstrated the effectiveness and the potential of analytical methods for the reliability evaluation of a renewable power system [10].

In the framework of the PV reliability assessment the present paper aims to perform a degradation study of the PV plant located at the Campus of the University of Salento by analytic approach that requires simulations of output power in order to compare the actual measurements collected on site and the theoretical output power. The theoretical model was implemented by using the PVsyst software [11]. The expected power generation index, defined as the ratio between actual output power and expected output power, is introduced to quantify the degradation and to evaluate the reliability of the PV system.

2. Methodology

The present study is performed using the measurements related to the PV system, located in the campus of the University of Salento, Italy and collected from 05 March 2012 to 31 December 2016. More details of the PV plant are provided in [12]. An integrated data acquisition system allows the monitoring of the main parameters of PV system. A first class LP PYRA 02 pyranometer is used for the measurement of the solar irradiance on the plane of the array and a PT100 temperature sensor measures the ambient temperature. The PV power and solar irradiance are processed and recorded every one minute by a SCADA system, meanwhile ambient temperature is every 5 minutes. An exhaustive description of the data acquisition system is given in [13].

A method to assess the degradation of the system is to determinate the difference between the measured output power and the theoretical output power.

In the present study, the theoretical model is provided by PVsyst that is powerful software of grid-connected PV systems, able to perform detailed hourly simulations. Previous studies demonstrated that the simulations carried out by PVsyst give a good approximation of measured power output [4], [14]. PVsyst uses the one-diode model to describe the operating of a PV module, including the effects on the diode current due to the cell temperature. PVsyst takes into account also the thermal behaviour of the PV array that depends on the ambient temperature and the incident irradiance. More details of the theoretical model implemented by PVsyst are given in [14].

Furthermore, PVsyst offers relevant tools to convert and to import measured data. The “Importing ASCII files” section constructs a set of hourly data, either for meteo and for project variables, generated from any way sampled data. Therefore, such function was implemented to convert the monitored data records of solar irradiance, ambient temperature and output power with the same sampling step of one hour. Afterward, all components of the system as the modules, strings, inverter, up to the connection to the grid and loss rate were set in order to characterize the PV plant under study in PVsyst environment.

The hourly expected power generation index I_E has been introduced to quantify the degradation and to assess the reliability of PV system, as follows:

$$I_E = \frac{A_P}{E_P} \quad (1)$$

where A_P is the available power output as measured data and E_P is the expected power output as theoretical data. The index I_E weighs the distance of theoretical and measured power values. High index I_E demonstrates a good agreement between them. Hence it is possible to assert that the PV system shows high reliability, when actual and theoretical power values are very close. Low I_E means that the actual power is lower than the theoretical power due to the performance losses or shadowing effects or to partial/full failure or outage.

3. Results and discussion

The monitored meteo data were resampled through the PVsyst to get the hourly meteo data. Successively they were used as meteo data input to simulate the PV system. Then the hourly samples of the theoretical output power obtained by PVsyst and those of the measured power were compared for each year. The analysis was carried out on filtered data, not including records available during the night. The correlation coefficient was adopted to carry out the investigation. Pearson's correlation coefficient R^2 is one of the most commonly used correlation coefficients and it is able to measure the linear relationship between two variables. Fig. 1 shows the correlation coefficients between the measured and simulated output power for each year. R^2 varies between 0.982 and 0.988 over the years. High coefficients show that the actual power is very close to expected power, demonstrating the PV system works very well.

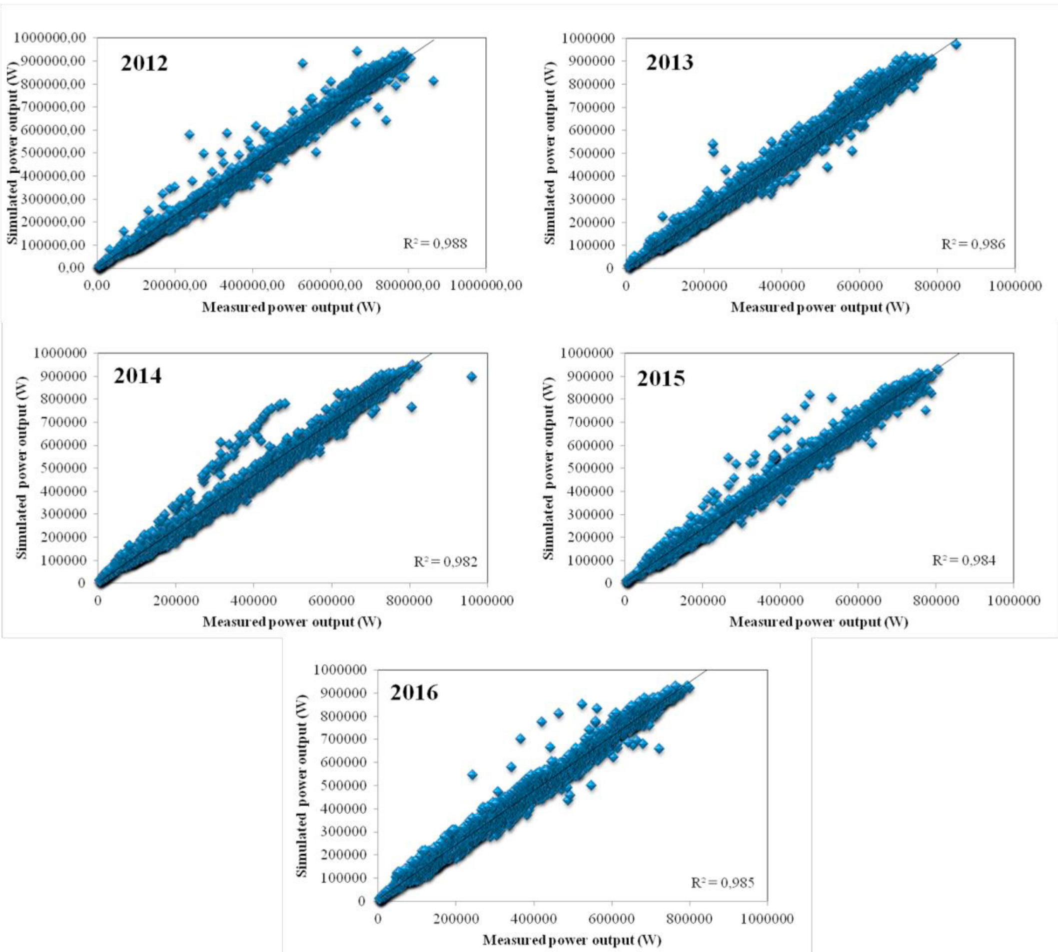

Fig. 1 Comparison between measured and simulated power output

In order to investigate the effect of the meteo conditions on the operation of the PV system, the Fig. 2 depicts the correlation between the solar irradiance on the plane of the array and the power output in both measured and simulated power cases. As expected, the theoretical power is well related to the irradiance (R^2=0.999). This means that there is an absolute correlation between two variables. In the case of the measured power the correlation coefficients are established of 0.98 during each year. It signifies that the measured power and the solar irradiance have a high positive relationship, in other word when irradiance increases (or decreases), the power increases (or decreases) with the same magnitude for each year.

An approach to identify the effects of ambient conditions on the reliability of the PV system is presented in Fig. 3 where the hourly expected power generation index I_E is plotted as a function of the incident solar irradiance. Very low coefficient correlations mean that there is no correlation, then the index I_E is not influenced by meteo data input. Therefore the differences between the measured and theoretical power, if exist, are not due to the meteorological conditions, but their causes have to look for within the PV components and the whole system operation.

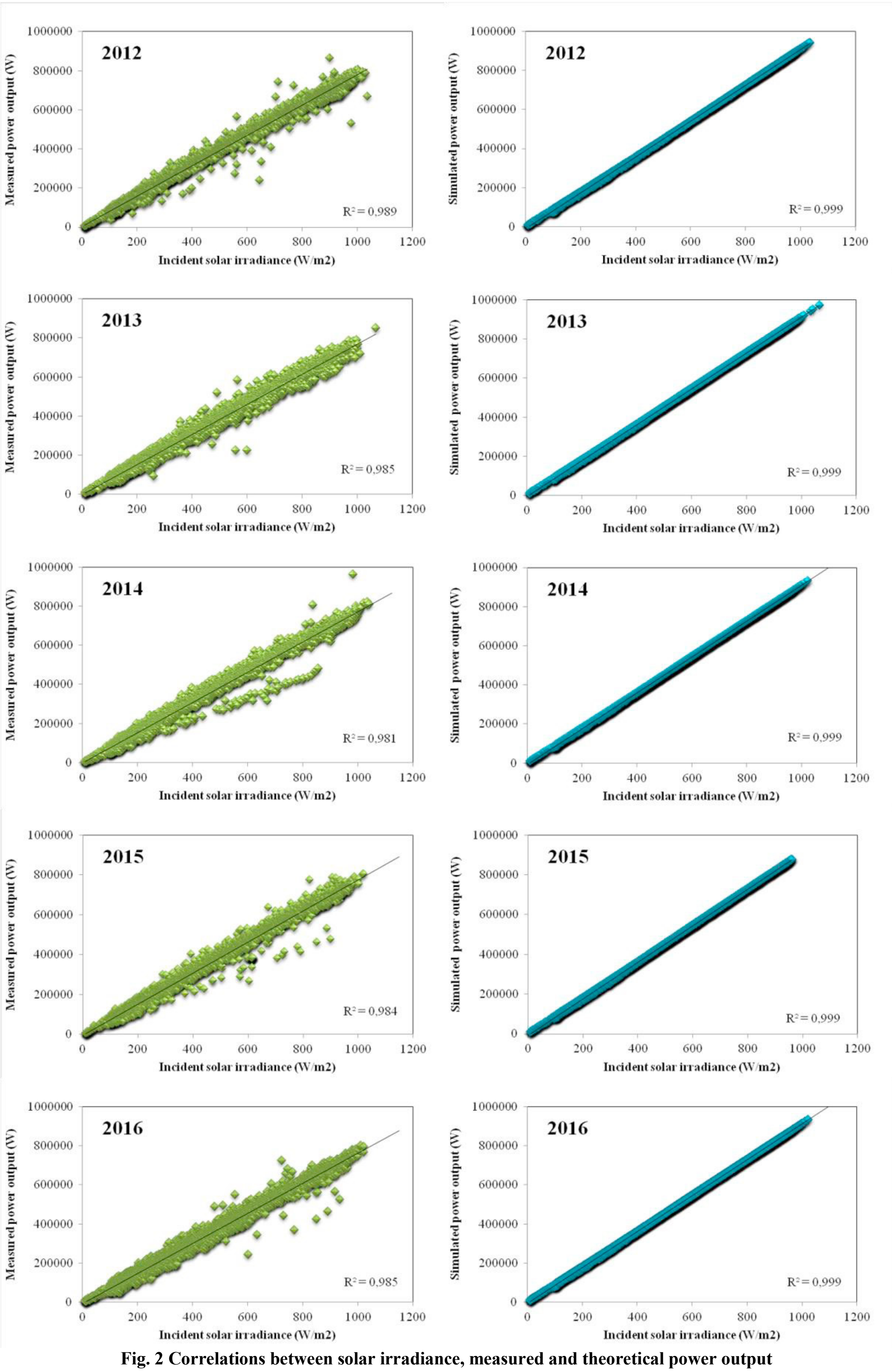

Fig. 2 Correlations between solar irradiance, measured and theoretical power output

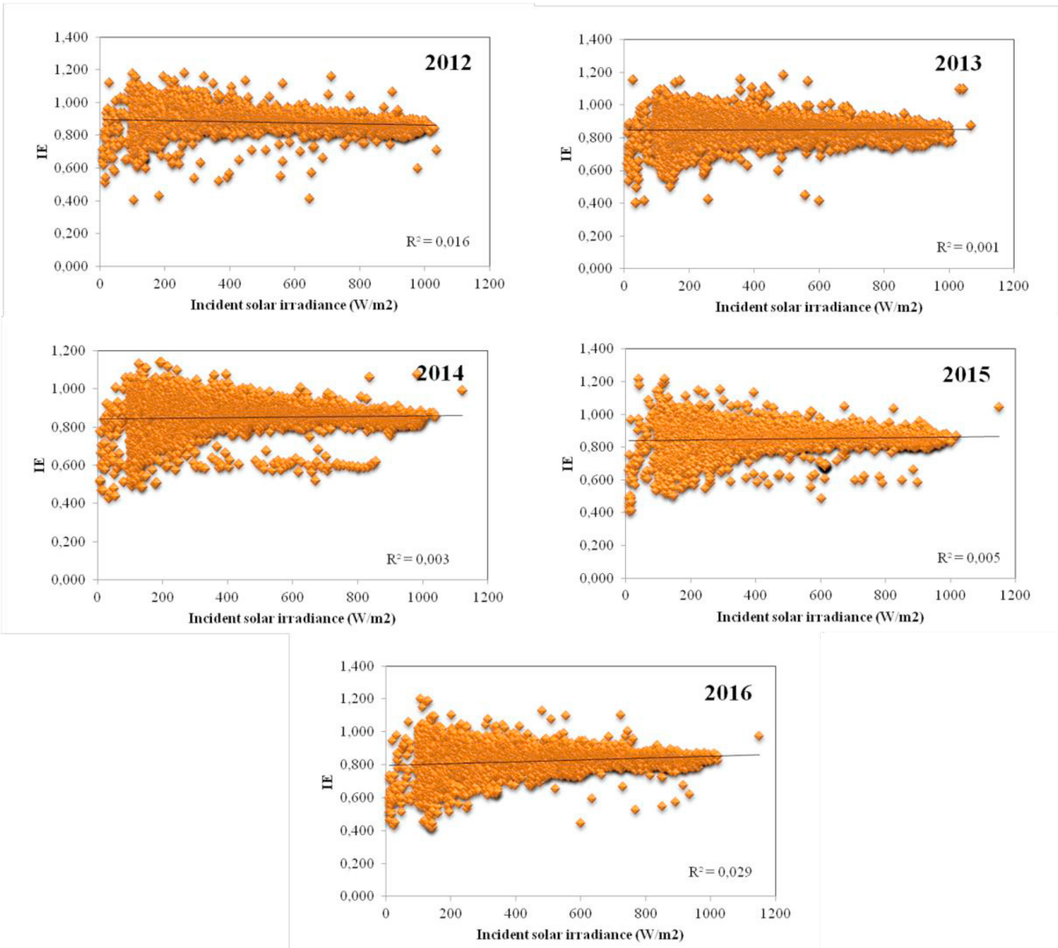

Fig. 3 The hourly expected power generation index I_E VS the incident solar irradiance

The index I_E ranges from 0.4 to 1.2. Table 1 reports the yearly mean of the index I_E for each year. Results show that annual averages of I_E are lower than 1 (perfect case). This means that exists a difference between the theoretical and actual power output due to adverse operating conditions which do not depend on the weather conditions. Furthermore, the index I_E is very close to 1 and it is always higher than 0.8 that implies a good according of both actual and theoretical power. So the index I_E represents the reliability level of the PV system, established to 85% on yearly average.

Table 1 Yearly average of the index I_E

Year	2012	2013	2014	2015	2016
I_E	0,880	0,849	0,850	0,849	0,824

Furthermore the index I_E decreases over the years. This trend indicates that the difference of the measured and theoretical power increases during the years. This is not affected by the weather conditions, so it is demonstrated the exiting of the PV system degradation over time. The yearly degradation rate of the PV system can be estimated at about 1.12%/year. Such result is according to reference degradation rate of 1.48%/year as computed by the authors applying the Classical Seasonal Decomposition (CSD) method [4].

4. Conclusions

Degradation and reliability studies of a PV system are strategic tools to assess the performance of a PV system. This paper contributes to investigate the performance of PV systems in the Mediterranean climate, enabling a comparison study in different climatic conditions. The purpose of the present study is to investigate the degradation and the reliability of the PV plant located at the Campus of the University of Salento by a comparative analysis of measured and simulated output power. The theoretical model of the PV system was implemented by using PVsyst software. The hourly expected power generation index IE was introduced to perform the comparison. Results demonstrate the reliability of the PV system depends also on operating conditions which are not directly due to the weather variations. A good agreement between the theoretical and the actual power output allows quantifying the reliability of PV system up to 85%. Furthermore the degradation can be estimated equal to 1.12%/year over five years of outdoor exposure.

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